Early experiences from deep decarbonization pathways in the Nordics

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Meet the Energy Leaders
TU Delft Energy Initiative
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The quest of deep decarbonization

The pace of EU’s emission reductions need to be 4-folded

-0.8%/yr

-3.1%/yr

-1.8%/yr

Carbon sinks
What can we learn from the Nordics in the deep decarbonization?
Swedish Nobel Laureate, Svante Arrhenius (1896): “\(\Delta F = \alpha \ln (C/C_0)\)”

Prime Minister of Norway, Gro Harlem Brundtland (1987): “Concept of Sustainability”; “Our Common Future”

Government of Iceland (2001): “Moving to a hydrogen economy”

Government of Denmark (2012): “100% renewable energy by 2050”

Photo: Anders Hellberg, 2018
Energy powerhouse
Preconditions for decarbonization

MAX-MIN in EU: Carbon intensity of economy ~ 10 ×; Wealth ~ 10 ×
European energy mix

Non-fossil share in the Nordics 35-85%

Ref. Eurostat
Electricity mix in the Nordic region

Power mix comparison:

<table>
<thead>
<tr>
<th></th>
<th>EU</th>
<th>NL</th>
<th>Nordics</th>
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</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>12%</td>
<td>0%</td>
<td>54%</td>
</tr>
<tr>
<td>Fossil</td>
<td>49%</td>
<td>81%</td>
<td>10%</td>
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Integrated Nordic power market
– a remarkable systemic energy innovation from regional collaboration
## Renewable energy and CO$_2$ reduction targets in the Nordic region

<table>
<thead>
<tr>
<th>Country</th>
<th>Share of RES</th>
<th>CO$_2$ target</th>
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<tbody>
<tr>
<td>Denmark</td>
<td>100% by 2050$^1$</td>
<td>Carbon neutrality by 2050</td>
</tr>
<tr>
<td>Finland</td>
<td>&gt;50% by 2030$^1$</td>
<td>Carbon neutrality by 2035</td>
</tr>
<tr>
<td>Norway</td>
<td>67.5% by 2020$^1$</td>
<td>Carbon neutrality by 2050</td>
</tr>
<tr>
<td>Sweden</td>
<td>100% by 2040$^2$</td>
<td>Carbon neutrality by 2045</td>
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$^1$ Of final energy; $^2$ Of electricity; $^3$ RES present share
A Nordic Pathway to Zero-Emissions in Electricity


Regional and sector coupling

2040-2050
Carbon neutrality enters other sectors

Further sector coupling
More transmission capacity
New business models

Lock-in in new energy and el. exports to mainland Europe & UK

2030-2040
Export of elec. to EU

Large deployment of wind
Phase out of fossil fuels
Regulatory barriers removed
Business for flexible actors

2020-2030
Main energy transition

Nordic electricity sector decarbonized

Intra-Nordic coupling

Regional and sector coupling

CO₂-free Nordic energy system

Sustainable bioenergy
Negative emissions
Distributional effects

Regional and sector coupling
Nordic power transition scenarios
Key elements

- Techno-economic-social system modelling
- Market-driven transition (least-cost)
- Raising CO₂ price (ETS or domestic taxes)
- Sector-coupling (heat, mobility)
- Removing regulatory barriers
Nordic power transition scenarios

Key results

- CO₂-free Nordic power system by 2030
- Hydro+wind >80% of all electricity in 2050
- Wind power grows 5-8-fold
District heat generation (DH) with P2H sector-coupling
Factors affecting social acceptance:

- Physical properties
- Economic properties
- Supply chains or infrastructures
- Geographical context
- Interaction/combination of factors

Social acceptance at different levels of the society

- Socio-Political Factors: Strong institutional capacity, political commitment, favorable legal and regulatory frameworks
- Market Factors: Competitive installation/production costs, mechanisms for information and feedback, access to financing
- Community Factors: Prolific community/individual ownership and use, participatory project siting, recognition of externalities or positive public image


Social aspects of the transition

Case: More transmissions lines & on-shore wind power
   a. Distributional effects from the Nordic transition
   b. Impact of social rejection of climate-friendly solutions


HighHigh = No limits
LowWind = On-shore wind restricted
LowTran = Transmission lines restricted LowLow = Both restricted
Distributional effects

Context: Stronger cost-optimal interconnection from the Nordics to the mainland Europe in 2050 without restrictions (HighHigh)

Producer revenues

Consumer prices
Effect of social acceptance restrictions on electricity price

Lower social acceptance leads to higher costs

Price change %

-30  -25  -20  -15  -10  -5   0   +5  +10  +15  +20  +25

Finland

<table>
<thead>
<tr>
<th>Price (Euro/MWh)</th>
</tr>
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<tr>
<td>50</td>
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No limitations
HighWind, HighTrans

LowWind

LowTransmission
Energy transition as socio-technical transition

Co-evolution of 3 semi-autonomous interactive systems affect the energy transition

① Techno-economic
① Socio-technical
① Political (actions)

Nordic power transition scenarios

Key elements:
 Techno-economic-social system modelling
 Market-driven transition (least-cost)
 Raising CO\textsubscript{2} price (ETS or domestic taxes)
 Sector-coupling (heat, mobility)
 Removing regulatory barriers

FINLAND = Green Gold
Finland is one of the first countries aiming at carbon neutrality by 2035

Elements of the policy framework:
- Anticipation of the EU policies
- Electrification
- Biotic carbon sinks (forests)
- Participatory sectoral roadmaps
- Just transition
- Green recovery package
- Climate legislation
  - Coal ban, halving oil use by 2030
  - Climate Law (2021)
- Negative emissions after 2035
Major changes ahead in the energy sector

Energy sector represented 75% of the emissions in 2018
Example of implications from a 72% emissions cut by 2035

- No coal, oil halved, peat and gas marginal
- Fuel (bio) needed to replace some fossil-fuel
- Strong electrification
- More wind power and heat pumps
- Less Combined Heat and Power (CHP)
- More biofuels (30%) and EVs (20%) in transport
Emission reductions required to reach carbon neutrality in Finland by 2035

Maths of net-zero emissions =

\[(X) \text{ non-energy sector} + (Y) \text{ energy sector emissions} – (Z) \text{ carbon sinks}\]

### Present net-zero emissions

- **2017**: 29 MtCO\(_2\)
- **2018**: 42 MtCO\(_2\)

### Year 2035 net-zero emissions:

- **X+Y-Z=0**
- **Z=20-21 MtCO\(_2\)**
Highlights

1. Countries are not equally well positioned for carbon-neutrality than the Nordics

2. Carbon sinks should not be overlooked

3. Electrification is important, but clean fuels are still relevant

4. ‘Being different but acting together’-rule provides comparative advantage to all

5. Social aspects should to be properly considered in the policy framework
Thank you!
Extras
Scenario of emission cuts in the energy sector

Now: 42 MtCO₂

## PRIMARY ENERGY SOURCES
- Oil: 22%
- Coal: 9%
- Natural gas: 6%
- Peat: 4%
- Nuclear: 19%
- Hydro: 4%
- Other: 10%
- Waste: 2%
- Wind: 1%
- Industrial wood residue: 17%
- Others: 2%
- Heat pumps: 2%
- Electricity import: 2%

## ELECTRICITY SOURCES
- Net import/export: 9%
- Conv. cond. power: 15%
- Hydro power: 18%
- Wind power: 6%
- CHP-ind: 11%
- Nuclear power: 27%
- CHP-DH: 15%

## HEAT SOURCES
- P2H: 1%
- Heat pumps: 10%
- RES-Heat from electric boilers: 18%
- RES-Heat from fuels: 13%
- Separate thermal production: 22%
- CHP-DH: 33%
- CHP-ind: 3%

### 2035: 12 MtCO₂

## PRIMARY ENERGY SOURCES
- Natural gas: 1%
- Oil: 11%
- CHP-DH: 7%
- Industrial wood residue: 21%
- Other wood: 12%
- Waste: 3%
- Solar PV: 1%
- Biogas: 2%
- Agro-biomass: 5%
- Others: 8%
- Heat pumps: 3%
- Electricity import: 3%

## ELECTRICITY SOURCES
- Net import/export: 12%
- Hydro power: 17%
- Wind power: 37%
- Solar PV: 2%
- Nuclear power: 16%
- Other: 12%
- CHP-DH: 7%

## HEAT SOURCES
- Heat pumps: 20%
- RES-Heat from electric boilers: 13%
- RES-Heat from fuels: 14%
- Separate thermal production: 4%
- CHP-DH: 20%
- CHP-ind: 1%

### Graphs
- Primary energy
- Electricity
- Heat
- Transport

2035 vs 2017
Decarbonization of deep fossil urban energy

Case Helsinki
Deep decarbonization of urban energy

Targeting carbon neutrality by 2035: 80% emission reduction + 20% carbon sinks

Present fossil-fuel shares in Helsinki:
- Heating 89%
- Power 65%
- Transport 91%

Mosaic of measures:
- Large-scale deep and sea heat pump schemes
- Large underground thermal storage
- Waste heat utilization
- Building energy efficiency and services
- Compact urban planning
- Electric mobility, trams, bicycle lanes
- Helsinki Energy Challenge
- Off-shore wind power shares, minimize bioenergy

Present fossil-fuel shares in Helsinki:
- Heating
- Power
- Transport

14 TWh/yr

Helsinki Energy Challenge

Heating (50%)

Oil

Gas

Nuclear

Coal

Power (30%)

Trans (109%)
Energy highlights

① The pathway to carbon-neutrality is dominated by the energy sector, but the non-energy sectors and carbon sinks need attention as well;

② Deep decarbonization involves large changes in the present energy system:
  - Large changes in a relatively short time may increase uncertainty and risks
  - Security and resilience of energy may need more attention
  - New infrastructure and investments required, industry’s investment cycles

③ Electrification promising strategy, but fuels should not be overlooked (e.g. in transport and industries);

④ Overlooking social aspects may lead to costlier energy solutions, both for the business and consumers.
General observations

① The conditions for deep decarbonization very much vary among the countries.

② The Nordic region is in a good position for carbon-neutrality; first-mover experiences on decarbonization will benefit all;

③ Much leverage from the Nordic framework, 'being different but acting together'-rule provides comparative advantage to the countries;

④ Market signals not always reach the market actors, i.e. stronger policies can be necessary;

⑤ Deep decarbonization of our societies are both a huge technical and social transition, which should to be properly considered in the policy framework;

⑥ Global warming concerns us all, it is our common responsibility to help less-fortuned countries and citizens in decarbonization.